DISCUSSION

PRESSURE FILTERS[1]

By Harold C. Stevens.

Dr. W. P. Mason: The speaker has always been prejudiced against the pressure filter, although he cannot help feeling that his prejudice is not well founded. It may be merely because he likes to see "the wheels go round" that he prefers an open filter. It must be acknowledged that the pressure filters have a large field of usefulness, although the speaker never liked them, though he has seen excellent results from such filters and they are unquestionably of smaller cost; but, as before stated the desire to see the inner workings of a plant is the only reason the speaker can offer for preferring an open filter.

We are looking forward to some day putting in a filter at Troy, and can easily understand how a pressure filter there would be better for our conditions than one of the ordinary gravity type, as we have several sources of water supply, three in fact, each of them drawing from a different level. Undoubtedly we would be better fitted with filter accommodations if we put in the pressure type.

Has the writer of the paper any preference with reference to the methods of getting rid of the air when he uses the air wash? How are you going to get it out of the filter?

Mr. Harold C. Stevens: The waste water pipe, arranged to discharge into an open funnel, is probably the most usual means for releasing air from an air washed pressure filter. A separate valve can easily be provided for emitting the air, where the waste water pipe is not adaptable, and it would not appear to be a difficult matter to make this valve automatic.

Mr. C. Arthur Brown: How is the proper degree of coagulation obtained in a pressure filter? In some pressure filters there has been difficulty getting regulation of coagulation within the shell; being broken up when it is introduced into the filter beds, it does not

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hold so well, apparently, as in the gravity type where the coagulation is brought into and onto the bed without so much breaking up of the particles.

MR. HAROLD C. STEVENS: The preferable way, where feasible, is to provide a separate coagulating basin, such as is used with a gravity filter.

MR. C. ARTHUR BROWN: In that case you would pump from the settling basin through the pressure filter?

MR. HAROLD C. STEVENS: Yes. There is no doubt that the coagulum is broken up by pumping, but to the speaker this is not a serious objection. The efficiency of the pressure filter does not seem to depend so much upon the condition of the floc as does that of the gravity filter. The speaker has not yet learned of an instance where trouble from this cause has arisen with pressure filters.

In some cases a reservoir higher than the filters affords opportunity for coagulation and the delivery of water by gravity without severe agitation. It is well, nevertheless, to avoid the breaking up of the floc as much as possible.

MR. J. W. LEDOUX: The speaker has read with interest the paper of Mr. Stevens on pressure filters, and notes his favorable opinion regarding their application and suitability. His conclusions are no doubt strengthened by the large amount of operating statistics that he must have obtained in various parts of the country.

There has been a considerable feeling against pressure filters, in some cases possessed by engineers who desire to maintain a reputation for adhering to the most conservative and popularly accepted design in water works purification. It is rather disappointing that the author did not show the results of several important installations, which he no doubt has in his possession.

The main advantage of pressure filters is their applicability in many cases where by their use low service pumps can be eliminated, with a consequent material reduction in cost. In the horizontal type, it is not so easy to design a satisfactory strainer system as with gravity filters or the vertical type of pressure filters, which is due to the curved sides and ends of the horizontal filters. In fact, this is the only valid objection to pressure filters. The strainer system of

any filter plant has not, by any means, reached perfection, and any feature that adds to its difficulty is objectionable. Nearly every experienced water works engineer has designed at least one strainer system, with which he later becomes more or less disappointed, and this applies not only to pressure but to gravity filters.

It would seem that the simplest and most satisfactory strainer system would consist of a manifold, with pipe connections having $\frac{1}{4}$ or $\frac{1}{2}$ inch openings pointing downwards, the whole being surrounded by a layer of broken stone or large gravel graduating upward to small sizes, the entire layer being as thick as possible, the upper portions of this layer to be high in specific gravity as compared with the sand.

Such material as lead shot is expensive, and engineers generally are content to use such graduated gravel as is readily obtainable in the market. The consequence is that unless some artificial method is adopted to keep the gravel in place, it may at some time be displaced. It is a well known fact that particles of small size are lifted in inverse ratio to some positive power of their diameters. For instance, particles of lead $\frac{1}{32}$ of an inch diameter would be lifted with an upward velocity that would not move ordinary gravel $\frac{1}{4}$ inch in diameter. The speaker has never made any investigation as to whether particles of a spherical shape would be more liable to remain in place than those of an angular shape. Ordinarily, however, if the water has a uniformly accelerated velocity, and the bed of gravel is of normal condition, it will remain in place very satisfactorily, and thereby prevent the sand from dropping down into the interstices. One of the great difficulties is due to accumulations of air which suddenly shoot up through the bed, displacing portions of the gravel, and temporarily destroying that part of the strainer system.

More or less successful attempts have been made to separate the gravel from the sand by means of a perforated plate held down by wire fasteners to the lower manifold system. Any device of this kind that will keep the gravel from moving at local points is of value.

There are a large number of brass strainers any one of which may give first class results for a considerable period of time, but they nearly all deteriorate under certain conditions, whereof the quality of the water probably is the cause; and even pure copper is subject to the same trouble.

Objections have been made to pressure filters on account of their not being readily adaptable to the use of rate of flow controllers,

but there are controllers on the market which are used very successfully with pressure filters; and today there is no difficulty in equipping these pressure filters with rate of flow controllers, loss of head and rate of flow gauges, and even sterilizing devices. One plant with which the speaker is familiar has pressure filters working under pressure from 130 lbs. to 150 lbs. per square inch. The filters are washed at the rate of 15 to 20 gallons per square foot per minute by gravity, the water being taken from a wash water standpipe located some 40 feet above the top of the filters. After the water passes through the filters it goes through a mile of pipe to the distributing reservoir located above the highest point of the town. Liquid chlorine is discharged into this effluent pipe on the town side of the filters by means of a small pump having a capacity of about $2\frac{1}{2}$ gallons per minute, and the discharge of this small pump is diluted to about one part of chlorine to 10,000 parts of water, or about 100 parts per million.

In conclusion the speaker is of the opinion that the gravity type of mechanical filters is generally to be preferred:

First, because they are cheaper to construct.

Second, because they are more readily accessible for repairs.

Third, because they are adaptable to the economical utilization of floor space.

On the other hand, the water purification results are exactly as good with the pressure type, and where the avoidance of double pumping is an important desideratum, engineers should not hesitate to use pressure filters.

In regard to the coagulant and the difficulty about the pumps dissipating the floc, the speaker is positive there is nothing in that at all. The results are equally good so far as the sulphate of aluminum is concerned. In one plant having a capacity of 5,000,000 or 6,000,000 gallons per day the sedimentation basis is of about 10,000,000 gallons capacity. Aluminum sulphate is fed into the basin directly, from which the water is discharged into the suction well and afterwards pumped through the pressure filters. Very accurate statistics are kept of the plant, as to the bacteria presence of B. coli and everything pertaining to a filter plant. The raw water shows an average of about 1000 bacteria per cc.; and the final filtered water shows an average of about 15; and that is the result of only four or five years' continuous operation.

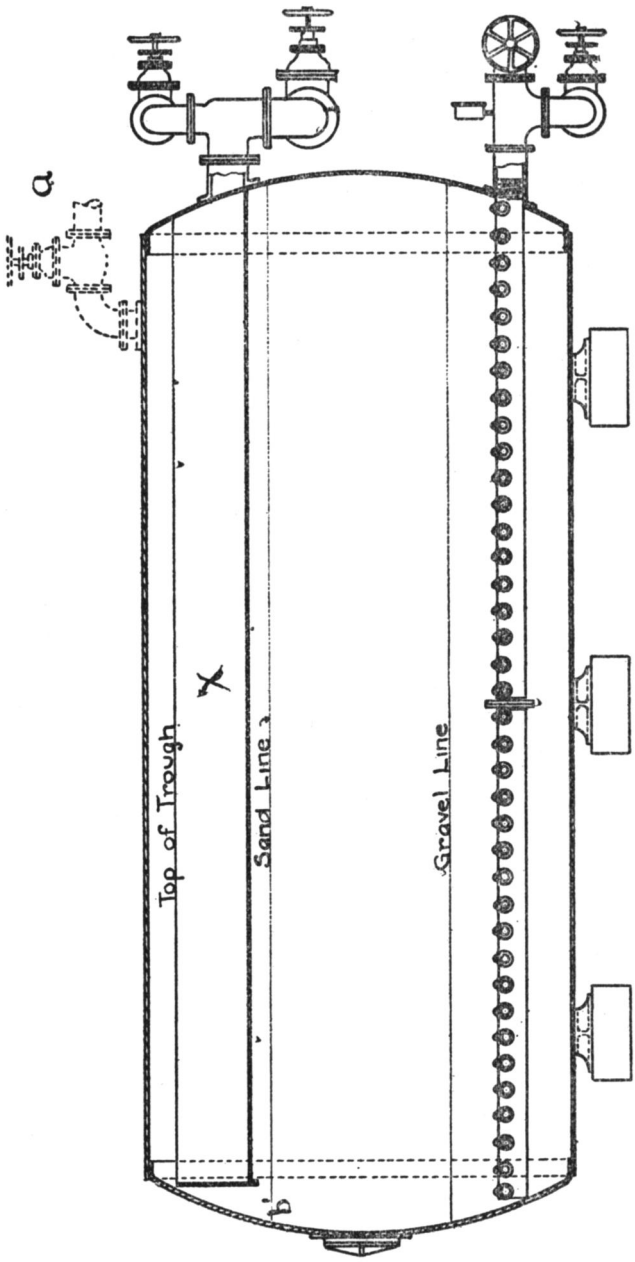
These filters have been in use for thirteen years. On the same

water system there is a modern type of gravity filter, and the most complete apparatus for producing efficiency and comparing results as to turbidity and bacteria. While the raw waters are substantially the same in quality, the difference is slightly in favor of the pressure filters; but that difference is so slight that it is considered insignificant. It simply shows that with pressure filters under proper management excellent results are easily obtained. Where there are other things of importance, such as the avoidance of low service pumps, the speaker would not hesitate for a moment to put them in, but for all types of filters the sedimentation basin should never be dispensed with.

MR. J. N. CHESTER: The speaker has looked upon pressure filters for purifying water very much as he does the air lift for raising water; namely, as a good thing to get along without, but a fine thing to have when you can do no better. It certainly then follows that he prefers the open gravity mechanical filter to the closed or pressure type, and in this preference he believes he is supported unanimously by the state boards of health or other bodies burdened with the duty of approving plans for filter plants intended for public water supplies, and the New York Conservation Commission has adopted a clause in its mandates or approvals which it thinks precludes pressure filters. It is, that a sight gravity feed must be provided for the coagulant.

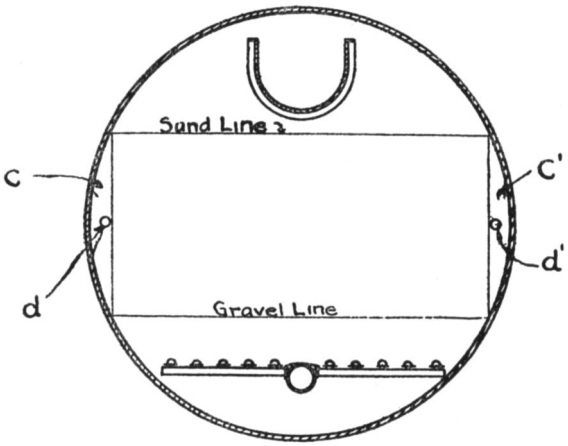
The speaker has never discredited or looked askance upon pressure filters he has encountered, installed and had in service, nor does he deny that good results can, with careful operation, be obtained; but has found that the difficulties of operating, especially on western waters are greatly multiplied over what they would be with gravity filters. Most writers dictate that a sedimentation basin shall be a part of any filter plant intended to clarify or purify, the capacity of which must be from one to four hours' quiescence period, and to provide this quiescence or sedimentation period is extremely difficult in connection with pressure filters; besides to pump coagulated water lessens the filter efficiency, since it breaks or almost pulverizes the floc and renders it less apt to be arrested by the sand.

As Mr. Stevens has shown, filters exceeding two hundred thousand capacity per day should be built cylindrical and placed horizontally, which adds to the difficulties. The cut used by Mr. Stevens was similar to the cut herein incorporated, with the exception that no



LONGITUDINAL SECTION OF PRESSURE FILTER

wash trough was shown, which represents the majority of horizontal pressure filters today in use. Now let any practical filter operator imagine the process of washing begun without the trough (x), but that the influent is admitted through the valve and pipe shown in dotted lines at (a), and imagine the path of a particle rising at the surface of the sand at (b). Experience led to the conclusion that cleaning the rear of such a filter was a practical impossibility, the result of which was the introduction of the first wash troughs used in pressure filters at East St. Louis, Illinois, which feature has been copied by some of the filter companies since that time.



CROSS SECTION OF PRESSURE FILTER

Another feature hard to overcome is the inability to wash the segment (c) and (c') shown in the cross section of the cylindrical filter. To overcome this it was found necessary to introduce 2 inch horizontal pipes (d) and (d') with perforations at such an angle that when water was introduced in them under pressure, it would agitate and remove deposits in these segments. Mr. Fuller can testify to such conditions at Hornellsville, N. Y., nearly twenty years ago, and in nearly fifty similar filters the speaker has since examined and labored to make efficient, the same difficulties have been found to be overcome as above described.

The speaker does not agree with the author of this paper that a good pressure filter plant can be built for $12,000 per million gallons, or that the average cost of gravity filter plants is $20,000 per million.

If as well equipped, the cost of the pressure plant will equal the cost of a similarly well built gravity plant. In either case you will get just what you pay for.

The speaker further takes issue with the author of this paper as regards the cost of pumping through pressure filters being greater, due to the increased head, than if the gravity plant was used and twice pumping employed, for the energy required to overcome the slight additional head is far less than the thermal losses due to twice pumping which the gravity plant requires. This of course is in favor of, and the only reason, from the speaker's point of view, why pressure filters should be seriously considered, and then only when settling facilities may be practically dispensed with.

In conclusion will repeat that it is admitted that, with the proper installation and care in operating, as good results may be obtained from the pressure filter as from gravity. No reason is apparent to look askance at or dispense with a pressure filter plant in operation, but the speaker is not enthusiastic, under 95 per cent of the conditions found, for the installation of pressure type filters.

MR. GEORGE W. FULLER: It would seem that perhaps the essential proposition involved in this question is whether the water under consideration must be subjected to the process of sedimentation before it is applied to the filters. If not, then mechanical pressure filters under many circumstances are more advantageous than gravity filters. That outcome is the exception, not the rule. When you have to deal with a very turbid water, which, for 10 or 20 per cent of the time throughout the year causes a filter without sedimentation to stagger under its load, then you have to figure with the necessary preliminary treatment, which will allow the filters to work most advantageously. If the local conditions are such that preliminary treatment is essential, then pressure filters may also present themselves for consideration, although they may require double pumping, which this style of filter is supposed normally to obviate.

In the speaker's practice he sees once or twice every year cases where pressure filters are strongly to be advocated as an advantageous means for purifying water. Rate controllers now make them more reliable than was the case in earlier years. At the risk of repeating the views of others, the speaker would say again that, other features and conditions being the same, a pressure filter will give as good service as a gravity filter. It must be admitted that

you have to watch it under rather more disadvantageous circumstances as to the point of observation, but, granting that you have the ablity to observe and record what the actual accomplishments are, then the same degree of coagulation, the same degree of turbidity, the same kind of sand, and the same efficiency in washing will give about the same result with either type of filter. The real question in selecting the type of filter is the significance of secondary pumping and of preliminary sedimentation. It is not necessary to argue that question here. It will have to be figured out in dollars and cents under each set of circumstances.

MR. F. B. LEOPOLD: There is one phase of this matter that has not been discussed by previous speakers which the speaker considers most dangerous and of sufficient reason of itself without consideration of any others, and there are many others extremely good and important. Pressure filters should not be advocated for municipal sanitary supplies and the reason is the fact that the average engineer in a small town, or water works superintendent of a small town, without considering the laymen at all has no conception of what filtration really is or will accomplish. He usually follows the lead of engineers of standing in the water field, and more often than not, even in this is not a very good imitator.

If, therefore, recognized authorities are found proclaiming as a fact that pressure filters are equally efficient to gravity filter installations, even in the proper limitation, the fact will soon become submerged, and the lower cost and greater apparent compactness and unit completeness of the pressure filter will appeal to the purchaser with the result that there will be a flood of installations of this type which will lead to absolute failure and rank waste of money. This phase should cause us to hesitate a long time about proclaiming efficiency of pressure filters.

As a matter of fact, this very condition, of course, has been gone through in the early development of filtration, and with all refinement that could be possibly put on or attached to pressure filters, their field is extremely limited, and only after the closest investigation of a water supply, and of the condition of this supply throughout the entire year, and with the necessary knowledge of the full limitations of pressure filters that can only be gathered by experience in their use, should they, under any conditions, in the speaker's opinion, be advocated.

There is no question that, with proper installation, proper operation and proper construction, they may be made to give satisfactory results. In fact, there are a number of well known pressure filter plants which are giving, even without the refinement mentioned, extremely efficient results. Nevertheless, these are only the exceptions that prove the rule and while from the manufacturer's standpoint the speaker would be inclined to welcome the use of pressure filters as a more profitable business proposition, as a quicker return on the money invested, outside of this purely selfish consideration and outside of the reasons given above, there are a dozen good reasons why he cannot agree with the writer of this paper that pressure filters should receive more consideration for sanitary supply than they do at the present time As a matter of fact, there are today being installed any number of them, some of them by pretty good engineers too; and some of them by manufacturers who know better, but are compelled by reason of competition to do it, plants which should not be put in, and which will only be abandoned in the course of a very few years, as have hundreds of those that have been installed in the past.

For the builders who do this there is some excuse. They have not opportunities to investigate fully and completely all conditions under which they are installed, but must depend largely on the word of the purchaser as to a very large part of the necessary information to intelligently advise them, and must have in view what the competitor will do also.

For the engineer there is no excuse. He is employed by a city or an individual to advise them what is for their best interests and he is, or should be, paid for the necessary time to fully and completely make the necessary investigations to intelligently advise them.

The speaker does not believe a discussion of the details of construction is of any value here, for the reason that he does not believe that there is any possible method of constructing the pressure filter that will make it a subject for serious consideration except in very isolated instances.

MR. DOW R. GWINN: Like Dr. Mason the speaker was once prejudiced against pressure filters. From 1892 to 1901 he lived with a gravity plant on the Mississippi, and came to the conviction that a mechanical gravity plant was the only kind, but when transferred to Terre Haute found the pressure filters there, and had to

overcome his prejudice, the pressure filters being there he had to get results out of them.

Now "the proof of the pudding is in the eating," and the actual results obtained from a pressure filter are what you must go by. Not that a pressure filter will answer in all cases; it depends entirely upon the character of the water that you have to handle. After all, when it comes to the last analysis, the success of a filtration plant depends upon the kind of water that is applied to the filter bed, that is, the condition of it when it is applied.

When they first began building pressure filters a great many years ago, they did not know much about sedimentation. That also applied to the gravity filters. They did not provide sufficient sedimentation for the western waters.

The plant in Terre Haute was first put in in 1889, with no provision for sedimentation, and the results were not always satisfactory, because at times the waters became very turbid and would run up as high as 3000 ppm.; but the most of the year the turbidity would only be about 25 ppm., so that one pump was all that was necessary. In 1891 a large sedimentation basin was put in, in order to get rid of the heavy suspended matter present at times when the river was turbid; the basin was used 25 per cent of the time, one year it ran up to about 50 per cent. Of course, a great deal of fuel was saved on account of the single instead of double pump.

Now, since the first of the year examinations have been made of 10 cc. samples; and out of 152 samples only 8 showed positive for B. coli. During the same period there was only 1 positive B. coli, in the 1 cc. samples, certainly very remarkable results.

On the other hand, the question of typhoid fever mortality would come in, and by the official records the average for the past five years was at the rate of about 25 per 100,000 population. During that period there were only a very small number of fatal cases on premises supplied with filtered water; leaving out the imported cases, and the cases where they used water other than city water, there were only 3.9 per 100,000 population; showing that as far as the results are concerned they can be obtained with a pressure filter plant.

There are some reasons why the gravity plant is better. The speaker, like Dr. Mason, "wants to see the wheels go round;" wants to see the wash water coming up through the filter bed; but in many cases a pressure filter plant can be used to very good advantage.

The Terre Haute results will show what can be accomplished with a pressure filter, and are given here as actual experience with a pressure filter plant, operating on a Middle West river water.

The Terre Haute Water Works Company. Pressure filters, operating results for a five year period, 1911 to 1915 inclusive

	1911	1912	1913	1914	1915	AVERAGE OF AVERAGES
Average turbidity, raw	121	172	115	55	95	111.6
Average* million gallons filtered daily	4.47	4.39	4.92	5.31	4.98	4.81
Average† g.p.g. alum used	2.07	2.36	1.64	1.40	2.14	1.92
Average pounds hypo	.....	10.1	9.5	8.4	.....	9.3
Cost chemicals per million gallons	$2.88	$3.40	$2.18	$1.69	$1.65	$2.36
Average alkalinity, filtered	180	164	180	170	175	174
Average color, raw	20	28	26	26	30	26
Average color, filtered	13	17	15	17	17	15.8
Average bacteria per cubic centimeter, raw	1147	2530	1767	1250	1637	1667
Average bacteria per cubic centimeter, filtered	63	39	42	65	35	48.8
Average filtration efficiency	94.4	98.4	97.1	95.0	97.8	96.5
B. Coli in raw (daily analyses), per cent of times 1 cc	76.0	66.0	67.4	53.3	68.3	66.2
B. Coli in filtered (daily analyses), per cent of times 1 cc	6.0	1.9	2.2	2.6	2.1	2.96

Note; Above bacteria counts in filtered water include those when filters had growths in August, 1911, and July and August, 1914.

* Not deducting slippage.

† Average price alum per 100 pounds f.o.b. T. H. {1911, $.93; 1913, $.87 / 1912, .93; 1914, .84 / 1915, $.846}

Add labor cost of $.08 per 100 pounds for unloading.

Pressure filters, Terre Haute, Indiana. Chlorine Gas and sulphate of alumina, March 14 to 19, incorporated. Using gas only for disinfection

DATE	KILOWATT	POUNDS SALT	BACTERIA PER CC.		B. COLI 10 CC.	ALUM G. P. G.
			Raw	Filtered		
March 14.....	90	80	1500	40	Neg.	2.20
March 15.....	93	85	1200	30	Neg.	2.21
March 16.....	80	75	1200	11	Neg.	2.00
March 17.....	89	75	900	40	Neg.	1.30
March 18.....	66	75	480	40	Neg.	1.14
March 19.....	92	65	420	15	Neg.	1.54
	510	455	5700	176		
Average.....	85	76	950	29.3		1.73

Hypo and chlorine gas in connection with sulphate of alumina. Average bacterial results

DATE	BACTERIA		B. COLI—FILTERED			
	Raw	Filtered	1 cc.	Number times		Per cent times positive
				Positive	Negative	
January.....	6850	67	1 pos.			
			30 neg.	3	28	9.7
February.....	2930	45.4	29 neg.	3	26	10.4
March.....	1520	31.3	31 neg.	0	31	0.0
April.....	1800	18.6	31 neg.	1	29	3.3
May.....	990	14.3	31 neg.	1	30	3.2
Average.....	2818	35.3				5.3

Terre Haute, Indiana, typhoid fever mortality

YEAR	DEATHS			POPULATION	RATE PER 100,000 AMONG CITY WATER USERS	RATE PER 100,000, TOTAL
	City water at residences	Well water only at residences and imported cases	Total			
1911			17	58,000		29
1912	3	13	16	58,000	5.2	27
1913	2	13	15	58,000	3.5	26
1914	3	12	15	60,000	5.0	25
1915	1	12	13	60,000	1.7	22
Total*.....	9	50*	76		15.4*	129
Average*....	2.3	12.5*	15.2		3.9*†	25.8

* Four years.

† It is estimated that 60 per cent of population use city water so that this figure, 3.9, would correspond to a rate of 6.5 if 100 per cent of the population used.

MR. ROBERT E. MILLIGAN: Mr. Stevens' paper opens up a subject that the American Water Works Association, and through them the water works world, will greatly appreciate when the matter is presented and full data supplied.

As many of you know, the speaker has had some experience in the purification of water through filtration, and has had some opportunity to examine the gravity and pressure filter plants installed and to note the results from same. He has been peculiarly situated to know the cost and operating values of both types. In endorsing Mr. Stevens' conclusions it is appreciated that these upset many preconceived ideas, and that it is not overstating the matter to say that the advocates of gravity filters have wholly lost sight of the practical phase of the matter. Mr. Stevens' paper is very general in its treatment of the subject, and an intelligent discussion should also be based upon general rather than individual instances, so that the question as to the merit of the pressure filtration plant and its general fitness becomes a matter of common sense following upon intelligent observation as to whether or not water can be purified equally well with the gravity filter as with the pressure filter, and which actually performs the work equally well with the least expenditure of time and money.

After having noted the results from many plants and with an understanding of the conditions under which filtration plants have been installed and are likely to be installed, the results are greatly in favor of the pressure filter. In all probability the attitude of the water works engineer in favor of gravity filters was and is due, first, to the fact that the original filters installed during the early purification period in this country were almost all pressure filters so that the abuses and failures incidental to a more or less crude method became a reflection on a particular class of filter rather than on the general method itself.

Second, until recently the control of the influent and effluent and the proportional amount of chemical under control was absent and only came into successful use through the gravity filter.

Third, the design, sale and installation of the pressure filter, like that of any other complete machine, is not so much an engineering problem within the jurisdiction of the engineer, as it is a direct offer of the manufacturer.

Fourth, the favorable trend of public opinion as to the use of sterilizing agents, following the use of sulphate of copper authorized by the United States Government, made possible a new factor in the purification of water that was wholly inadmissible in the earlier days when pressure filters were installed almost exclusively.

The use of hypochlorite of lime and chlorine following the Jersey City case further prepared the public mind for the direct use of chemicals in destroying bacteria irrespective of any cleansing method. And it may be stated right here that the filtration of water is essentially a cleansing method and that the purification resulting is due to the removal of unclean elements from the water itself rather than to their destruction; while sterilization is a destructive method rather than a removal method. No doubt exists in any of our minds that there is little if any competition between sterilization and filtration, but that they are together a method of completely purifying water. That is the practical side of the proposition.

It cannot be stated seriously that a gravity filter has any advantage over a pressure filter in removing bacteria. It could be and probably will be stated that gravity filters have shown in general a more perfect bacterial removal. To those who regard the matter in this light it should be pointed out that the bacterial inefficiency of certain pressure filters was not due to any inherent weakness so much as to carelessness and ignorance on the part of those controlling

them, who in many cases did not take the question of filtration seriously, but installed the quickest and cheapest method in order to satisfy an ill directed public clamor; but it is a matter of fact that in some cases a half million gallon pressure filter plant was installed on a four million gallon supply and 75 per cent of the water by-passed around the filter, the filter being there only to prove the willingness of the public service company to comply with the demand for filtered water. Happily, conditions to-day are such that the subject is now understood not only by the engineers and the practical water works men, but in a large measure by the general public, so that installations within the last ten years have been honestly advised to meet actual necessity. This, then, means that the same area of filtration will be installed in the case of pressure filters as in the case of gravity filters so that sound conditions may be established and comparisons can be made.

It is well understood now that the devices developed through the gravity filter for the control of the influent and effluent and applied chemical are equally applicable to the pressure filter. It is also true that, having the more or less perfect controls, either method can be installed and equal bacterial efficiency accomplished in the case of the pressure as with the gravity filter. .There are several cases in which such good results have been achieved that the use of a sterilizing agent has been virtually abandoned, and while the apparatus is retained it is only to meet some possible emergency due to an extraordinary condition. At Atlanta, Georgia, the use of a sterilizing agent has not been necessary for a great many months, and the pressure filters there installed are giving upwards of 98 per cent efficiency, the actual counts in the last six months in the filtered water averaging in the neighborhood of ten bacteria per cubic centimeter. This particular installation also makes it possible to localize a very great advantage of the pressure filter over the gravity filter, and that is its elasticity in cleansing a much greater quantity of water per square foot of area than would be possible with a gravity filter under similar conditions. It will be interesting to state that the bacterial results just cited have been accomplished at times by the Atlanta plant at twice the rated capacity. In other words, almost a complete cleansing and bacterial result has been obtained where the half million gallon unit of filtration has been operated at the rate of 1,000,000 gallons in twenty-four hours. It is not intended to convey the idea that a filter can be operated indefinitely in excess of its rated capacity

and its bacterial efficiency not be affected. In fact, experience shows that there is a more or less direct relationship between the rate of filtration and its bacterial efficiency, particularly with certain waters. This would now, however, be of little moment where sterilization could be depended upon to correct such variation, provided that the cleansing of the water is assured as well at the higher rate as is the case if the normal rate of 125,000,000 gallons per acre is used. It not infrequently happens that a city through municipal conditions beyond the control of the water department is unable to provide for a rational and steady increase in the productive end of their water works situation. Pumps are in many cases run at a greater speed in order to furnish a greater volume of water even though the efficiency of the pump is affected. Likewise, a pressure filter can be operated during such emergency periods to produce a greater quantity of filtered water, and it is a fact that the loss of efficiency in the bacterial sense where a 100 per cent increase in production occurs is not more than 10 per cent. This 10 per cent reduction in bacterial efficiency can be readily overcome during such emergency periods by the use of a minute quantity of sterilizing agent, such as chlorine. This condition is not similar in the case of a gravity filtration plant.

The pressure filter, while costing more per square foot of area so far as the filtration unit itself is concerned, is cheaper to install because of the elimination of the double pumping scheme and because of the avoidance of the clear water well as an essential part of the filtration project. In many cases reservoirs and standpipes have already been installed and the building of a clear water well is of no particular value so far as the practical operation of the water works system in general is concerned. Where a storage reservoir for clear water is essential it is as much a part of the general water works scheme as any other and is not particularly related to the filtration installation. It will be stated that sedimentation is a valuable and in some cases a necessary part of a properly designed filtration plant. This is quite true, but again it is as easily applied to a pressure filter proposition as to a gravity filter installation, that is to say, if it is necessary. It also rests on its own foundation and its location would in most cases determine in advance the advisability of installing pressure or gravity filters. This is intended to admit that there are conditions favorable to the installation of gravity filtration plants. There are also cases where the pressure filter is not only the most economical but the most practical method of purifying the water, and

in such cases it is uneconomical and inadmissible to install gravity filters. Unfortunately there exists a prejudice which has in some cases compelled the installation of gravity filters, and it is sincerely hoped that Mr. Stevens' paper may open up a discussion wide enough to satisfy the public service commissions, boards of health and engineers that no reason exists for this prejudicial exclusion.

In discussing a subject so many phased as this the character of the water to be treated is of the utmost consequence. For example, there is no doubt whatever that a highly colored water substantially free from suspended matter can be treated to better purpose through a pressure filter without subsidence. There is little or no doubt that in the treatment of waters containing iron under most of the conditions affecting iron waters this is also true.

It frequently happens that in the design of a filtration plant by an engineer retained by a city considerable money is expended on the building and construction work so that the filter can be observed by the operator. If this were of any real advantage it would of course be a good argument against the pressure filter which is enclosed and the operation of which can only be seen through such gauges and sight feeds as may be installed for the benefit of the operator. As a matter of fact, however, the function of a filter is to perform, and its performance can be controlled and observed as frequently as may be desired without resorting to the visualization of the surface water superimposed above the sand bed; nor would the actual observation, even if it were practised, affect the performance or give to the operator any additional safeguard affecting the performance.

Mr. Stevens' article could not have been taken seriously in the earlier days of filtration, but today there is no doubt that with the development of the Venturi tube and the regulation incidental to it a satisfactory control can be established, and the regulation of the pressure filter be made as exact as that of the gravity type.

In the washing devices there is no method satisfactory in the gravity type which is not equally applicable to the pressure type. There is, however, a limitation as to size in the use of the pressure unit due to economical development of the tank itself, it being practically impossible to construct a greater unit than will handle one million gallons in twenty-four hours at the normal rate of filtration. Many water supplies, as, for example, Scranton, Pennsylvania, have several sources, and the pressure filter in such cases would meet a condition that would be extravagant, to say the least, if gravity filters were employed.

So far as the life of the plant is concerned, there are actually in existence in the United States today pressure filters that have been in constant service for thirty years, and the material appears in excellent condition where any reasonable care has been taken of the plant. It is not improbable that a good steel pressure plant will last in all substantial respects as long as a concrete gravity plant. In view of the improvements to be expected it is reasonable in any case to expect that a filtration plant of either type that has served its purpose for forty consecutive years has fully met all the requirements, and the question of rehabilitation, increase or substitution would be substantially the same in either case.

MR. GEORGE F. CATLETT: When you bring up the question of pressure filters, you touch a sore spot with the health officials. This is due to the trouble experienced with the numerous small installations of this type that fail to give satisfactory results, and whose usual recommendation is that they are "fool proof" or can be operated with little trouble or attention. The usual idea is that you fill up the alum feed box, set the filter to running, and a pure water will follow. Experience shows that a very poor quality of effluent is obtained. The speaker is very strong in the belief that, even with a plant of 50,000 to 100,000 gallons capacity, you should have an operator who is thoroughly familiar with his purification process.

Mr. Fuller, in his discussion, suggests the importance of basin treatment. The large majority of raw water supplies have considerable quantities of color or turbidity to remove, and for this purpose the basin treatment before filtration is the most important part of the process. The filters will not accomplish the necessary results, and this part of the work should be performed before the water reaches the filters. For this reason it is important, even in the smaller plants, to have this part of the plant developed to the highest stage of efficiency, necessitating competent control by laboratory supervision. Proper basin treatment is not possible in connection with pressure filters, as has been admitted in the course of the discussion.

When we consider this phase of the matter, the speaker has not heard any advantages of pressure filters so far that will offset this serious objection, and compare with results obtained from efficiently designed, adequate coagulating basins, operated by intelligent operatives, and followed by filtration with gravity filters.

The speaker is not in a position to compare costs, and, in a body of this kind with so many water works manufacturers, would like to hear something further from them in this respect. The ideas of health officers are largely based upon quality of results obtained.

MR. H. C. STEVENS: The speaker does not claim that the pressure filter considered simply as a device for purifying water, has any general advantage over the gravity filter, but does believe that a pressure filter plant can be constructed more cheaply, and that, if it is equally well equipped and operated it will deliver just as good water. The figures given are of a general nature and are not based on a specific design, but they have been carefully considered, and they are sufficiently close for a broad comparison.

MR. J. M. DIVEN: Mr. Catlett says that he has not heard anything that tells him of any advantage to be derived from pressure filters. Though Mr. Milligan seems to have pointed out several, a case in point might be of interest, a real situation, one where a pressure filter is contemplated and advised. A gravity supply with ample pressure to allow for any loss in the filters; but so located that a gravity filter could not be installed that would not make pumping necessary, thereby greatly increasing the expense of operation and cost of construction. The supply reservoir has sufficient elevation to give the required pressure, allowing for the loss in the filters; but the outlet to the supply conduit is through a pressure tunnel one mile long, and to locate a gravity filter at the outlet to the tunnel would reduce the head more than consistent with good pressure in the distribution system. To filter this supply at the reservoir would make it necessary to install low service pumps to pump to the filters if gravity filters were used. The reservoir is twelve miles from the city and several miles from the nearest railroad, so that coal and other supplies would have to be hauled long distances, at large expense. On the other hand, if the water was filtered by gravity filters near the city the head provided by the location of the reservoir would be wasted and high service pumps would be required to give the desired pressure in the distribution system. With a gravity filter located at the reservoir wash water pumps would be required, as well as the low lift pumps, another item of expense that can be avoided by the use of pressure filters.

The water is low in turbidity, has long sedimentation and would

need no preliminary treatment for filtering by pressure filters. The only possible disadvantage, and this has been carefully considered, is that to provide for fire service, peak of load and other extraordinary demands the filter plant would have to be of greater capacity than a gravity filter having a clear water storage to take care of excess uses. But a careful weighing of this cost with the constant cost of operating pumps, constructing clear water reservoir and the necessary machinery for operating the gravity plant, shows a large saving in favor of the pressure type of filter. No more intelligent attendance would be required with one type than with the other. No municipal filter plant should be left to unintelligent management and operation. Does not this tell Mr. Catlett of a possible advantage in a pressure filter?

Small pressure filter plants are undoubtedly often left to the tender mercies of unintelligent management and operation; but in these cases a gravity type would be impossible, because it could not be operated at all without more attention than can be given to such pressure filters, and, while these poorly attended filters undoubtedly give poor results, they are better than no filters.

MR. GEORGE F. CATLETT: Mr. Diven seems to have misunderstood the speaker. Most of us can recall just such instances as he has cited. The Atlanta case has been brought out in the discussion. The point that the speaker was considering was the relative merits of the two types of filters in general. In all engineering problems there arise peculiar conditions which necessitate designs that would not be considered advisable in general practice. The case cited is one in which the peculiar local conditions prevent the use of the more desirable gravity filters and require the substitution of the pressure type.

Mr. Milligan has cited many desirable features in pressure filters, but the speaker wishes to emphasize the fact that for most water supplies, where basin treatment is important, the pressure is inferior to the gravity.

If pressure filters are reserved for the few special places where they are peculiarly suited there is no objection. The indiscriminate installation of them without regard to the nature of the problem, and the encouragement of their use in general in place of gravity filters, is a step in the wrong direction. It might be a very desirable proposition from the manufacturers' standpoint, but from the standpoint of efficiency of results a very poor one.

There are many who would take issue with Mr. Diven in the statement that the small filter giving poor results is better than no filter. The user of water from these has a feeling of false security; the speaker has in mind several pressure filter installations that are furnishing a poorer effluent water than influent water.

MR. GEORGE A. JOHNSON: Mr. Stevens' paper is suggestive and timely. It would seem that the pressure filter has hardly been given a fair show by water filtration men in general. When this type of filter first came under the speaker's observation during the Louisville experiments twenty years ago, while confessing that he knew less about filters in general then than now, he looked upon it as a sort of catch-as-catch-can arrangement, and unreliable. Well, in a general way it proved to be so in that case, but the method of rate control in that filter was elementary and encouraged trouble, and the filter had to work under about as bad conditions as normally are encountered.

The present day pressure filter of the advanced type is a great improvement over the pressure filter of twenty years ago, and it is being improved yearly. The speaker has great confidence that it will develop into a far broader field of usefulness in the near future than it has in the past. Its use is much more widespread than people generally have been led to believe. One hundred and fifty-one plants for municipal supply with a total capacity of 265 million gallons daily, is not an insignificant showing. Quite the contrary. The present capacity of all rapid sand filter plants for municipalities is something like 2000 million gallons daily, hence the pressure filter is represented to the extent of 13 per cent of the total, and this does not include the hundreds of pressure filters used for industrial service, hotels, residences and the like.

It is a quite notable fact that the pressure filter is looked upon with considerable favor by private interests. Of all the pressure filter plants for municipal supply over one-third are owned by private companies. Now all water works should be run as a business and on a business basis. The water department of a city is often a source of substantial revenue. Private water companies are certainly run on as efficient a business basis as possible, and as in all business, the first thought is to furnish satisfactory service at the lowest feasible production cost. To the speaker's mind the explanation is clear why so many privately owned filter plants are of the pressure

type. Their operators evidently are able to get good service for less money than they would be able to get with a gravity filter. This seems like a good argument for pressure filters.

There is another phase of the general subject of water filtration which favors the pressure filter. Sterilization is referred to, which in the last few years has come into almost general use. Consequently the water filter, *per se*, may now be looked upon essentially as a mechanical strainer; a device for removing suspended matter, and coloring matter which has been coagulated; and not as the highly efficient medium for removing bacteria sought for years ago.

Water filtration practice was revolutionized with the development of the art of sterilization with chlorine compounds. For years there was an insistent endeavor to develop sterilization by such agencies as ozone, copper compounds and the like. But they all failed, or were shown to be undesirable, until the hypochlorite treatment was placed on a sound footing in 1908-1910. Here was found a highly effective, easily applied and cheap method of sterilization. Its use spread like a prairie fire.

With the realization that a cheap and efficient, as well as easy method of sterilizing water had been found, one which had no bad after effects, the necessity for relying upon the water filter in itself to remove the dangerous bacteria from water passed away. The water filter was still needed to remove color and turbidity, but the really consequential phase of the bacterial side of the purification process could well be taken care of by sterilization.

Unquestionably the profoundest enemies of the pressure filter are those who consider it unreliable from a standpoint of bacterial removal. But now we must be fair and admit that the time is past when any filter need be required, or expected, to remove all disease bacteria, consequently the greatest objection to pressure filters is thus nullified. The idea persists, nevertheless, for even the author says in his conclusions:

> The pressure filter, as thus far constructed, is in some instances a very inferior means of purifying water hygienically, and in other cases an excellent means, but on the average it is not entirely reliable.

Here we have it again. It is in some instances an inferior means of purifying water *hygienically*. It seems to the speaker that so much emphasis should not be placed upon the hygienic deficiencies of the pressure filter, for filters of all types in municipal water puri-

fication systems are not selective in their action, and all of them pass disease germs at one time or another, and none of them ring a bell when they do so.

Further than this the speaker sees nothing important to criticise in the conclusions of the author. The pressure filter seems to be somewhat better adapted to the treatment of some waters than gravity filters; it is especially qualified to treat supplies small in volume; and the cost of construction is usually low in comparison with gravity filter installations. There is need that consideration be given to the pretreatment of waters applied to pressure filters, and certain construction details require attention, particularly as regards the elimination of "dead areas" in the sand bed, control of the rate of filtration, and maybe better washing facilities. With these features developed, so far as practicable, the speaker is firmly of the opinion that the pressure filter is entitled to a prominent "place in the sun", and that the future will see its use to a far greater extent than in the past, for the treatment of practically any water, and in practically any amount.

MR. HAROLD C. STEVENS (closing discussion): At the commencement of this closure the author feels that he must take exception to the editorial comments which appeared in the *Engineering News* on June 15, 1916. The statements are there made that his paper was a "remarshalling of the old arguments in favor of pressure filters," and that "the majority of speakers favored its use only under exceptional conditions." These are not altogether correct statements.

The first part of the summary's conclusion says "The pressure filter as thus far constructed is in some instances a very inferior means of purifying water, and in other cases an excellent means, but on the average it is not entirely reliable." The author's argument for pressure filters is conditioned on improved design, embodying controlling devices, similar to those provided for well-designed gravity filters, and including in many instances settling basins of adequate size. This argument is supported, in some cases very directly, by Messrs. Mason, Ledoux, Fuller, Gwinn, Milligan, Diven and Johnson. Messrs. Chester, Leopold and Catlett take an opposing view, apparently without considering the subject from the point of view of the author, but rather as dictated presumably by the results of their experience with pressure filters as usually equipped heretofore.

Most of the speakers expressed the opinion that the pressure filter with proper improvements and accessories will find a much broader field of usefulness than the pressure filter of the past, and other speakers felt that this field would be very restricted.

The cost of satisfactory filtered water is the crux of the whole question, and the author believes that pressure filters will prove the more economical in a surprising number of future installations.

Dr. Mason likes to see "the wheels go 'round." So does the author, and for many years he felt it was an advantage favoring the gravity filter to be able to see the wash water turn over on its way to waste; but now that engineers have learned how to lead off the waste water and how a sand bed "feels" when it is washing well or poorly, visibility and accessibility are not of much importance, except in the case of helping out a bad design by renewals of strainers or filtering material.

Mr. Brown and Mr. Chester have directed attention to the breaking up of the particles of coagulum when the applied water is pumped from a settling basin, and some additional remarks about coagulation seem to be appropriate here.

There may be said to be three ways of applying coagulant in connection with pressure filters:

First. Apply the coagulant in the supply pipe, relying upon the reaction taking place in the water above the sand. In this case a portion of the coagulant may pass undecomposed through the filter and cause the after appearance of hydrate in the effluent. This is, of course, more likely to happen with the waters which react slowly. The method is the most familiar one, but it will not go with muddy water, even if the floc formation is satisfactory, on account of too rapid clogging of the filter sand. In some instances it is permissible and even desirable, but it should be adopted only after most careful consideration.

Second. This is like the first, except that the applied water is passed through a closed reaction chamber, usually called a settling chamber, before going on to the filters. This chamber is too small to be of much account as a settling chamber. The only advantage of the method is that the reaction period is lengthened.

Third. Effect coagulation in a full-size open settling basin and pump the settled water to the filters. The problem of pretreatment is then the same as with gravity filters and the water applied to the filters is the same, except that the coagulum is broken up in passing

through the pumps. The author's opinion that the breaking up of the flocs does not impair the efficiency of a pressure filter to a considerable extent is sustained by Mr. Ledoux in speaking from very extensive experience.

Mr. Ledoux considers that the main advantage of pressure filters lies in the elimination of low-lift pumping, believing that otherwise the difference in cost will be in favor of gravity filters on the basis of equivalent equipment. This dampens the author's optimism somewhat, but he still believes that, even with an adequate open settling basin and double pumping, a pressure filter plant in a great many instances will be less costly to construct and operate than a gravity plant, and therefore looks upon the total cost as the basis of comparison. Mr. Chester holds that the costs of similarly well-built plants will be equal. Mr. Fuller considers cost the main consideration and rightly says that it will have to be figured out under each set of circumstances. Mr. Milligan and Mr. Johnson think that pressure filters have the advantage, therein confirming the author's view.

Mr. Ledoux is quite right in his criticism of strainer systems in general. A few may be termed almost satisfactory, but perfection has not yet been reached. The strainer system is the heart of a filter, and the designer must still bend his energies to its improvement, wherein lies the only hope of effectually eliminating displacement of filtering materials, and progressive accumulation of sediment within the filter bed.

The difficulty which the curved sides and ends of a horizontal filter shell present against obtaining uniform distribution of wash water can be eliminated by filling out the segments to a vertical plane, with no great difficulty and at no great expense.

Mr. Chester's comments regarding the attitude of state boards of health convey the idea that such boards are dead set against pressure filters. Perhaps this is true with regard to plants like most of those that have been installed heretofore, but the author does not believe that any such board would withhold approval of a well-equipped pressure filter design. He knows of one state board that is not opposed to pressure filters as such, and doubts very much if the requirement of a sight gravity feed is intended primarily, as Mr. Chester thinks, as a subterfuge to preclude the installation of pressure filters.

Mr. Chester explains that the collecting trough for waste wash

water is an important part of the pressure filter. It is essential to effect the removal of dirty water quickly, by the shortest path possible, in order to get rid of the sediment without needlessly and wastefully prolonging the period of washing.

Mr. Chester takes exception to the statement that "The cost of operation of pressure filters should be about the same as in the case of gravity filters, except that the cost of pumping may be a little greater, on account of the greater head utilized in the filter." The author had in mind pressure filters with open settling basins. The cost of single pumping is unquestionably somewhat less than double pumping, but the difference is only a very small percentage of the total cost of operation.

Mr. Leopold's views regarding pressure filters are pessimistic to say the least. The idea of discouraging the use of pressure filters for the treatment of municipal supplies simply because some inexperienced engineers may install poorly designed plants or because some filter manufacturers may foist an inferior plant on an unsuspecting community, is certainly not in the line of progressiveness. Mr. Leopold, with most evident sincerity, has rung in a false alarm. There are plenty of engineers who can design pressure filters creditably, and the prominent filter companies will undoubtedly lend their best efforts most effectively to raising the standard of pressure filters. State boards of health and the like, as is emphasized by Mr. Chester's views, can be depended on to block with disapproval the installation of plants that will fail, and so put an effective check on the inexperienced engineer and the unscrupulous manufacturer.

Mr. Gwinn's discussion is a welcome addition in substantiating the right of the pressure filter to a "place in the sun," quoting Mr. Johnson's expression, and he backs up his opinion with a comprehensive tabulation of results.

Mr. Milligan's support is very gratifying to the author as an impartial and thorough consideration of the pressure filter question by one who is exceptionally well qualified to regard it from the viewpoints of both the engineer and the manufacturer.

Perhaps the most important part of his discussion is that which deals with rate of filtration, showing that in many cases the rate may properly be increased to double the usual maximum rate for gravity filters. Sterilization is an effective safeguard against the comparatively small decrease in efficiency that results from the high rates.

The author does not unqualifiedly endorse such higher rates. They should be adopted only after a careful investigation of the character and variation of the raw water and of the conditions under which the filter is to be used. When a high rate is found to be permissible the advantages of the pressure filter over the gravity type will be unquestionable with regard to cost.

Mr. Catlett voices briefly the unkindly feeling of the public health officers towards pressure filters, but his last sentence, "The ideas of health officers are largely based on results," indicates that they are nevertheless open to conviction. There are a few pressure filter plants, built or building, that are what the author regards as up-to-date. It is to be hoped that the operating results of such plants, both as regards cost and efficiency, will be promptly published in engineering periodicals.

Exception is taken to one of Mr. Catlett's statements, namely, that "Proper basin treatment is not possible in connection with pressure filters." It certainly is just as feasible to provide an open settling basin in connection with a pressure filter, as it is with a gravity filter, at an increased cost, of course, which may or may not, leave a balance in favor of the pressure filter.

As regards efficient supervision, the requirements of pressure or gravity plants are identical.

Mr. Diven, and also Dr. Mason, tell of the situation at Troy where the conditions strongly favor the pressure filter. Evidently there will be no coagulating basin and, if Mr. Chester is correct, a sight feed for applying coagulant under pressure will have to be provided before the approval of the state authorities can be obtained. The author wonders if this will seriously hamper the project.

Mr. Johnson points out that, in view of the effectiveness of final treatment with chlorine compounds, high bacterial efficiency in filtration is not essential, and criticises the use of the word "hygienically" in the sentence "The pressure filter as thus far constructed is in some instances a very inferior means of purifying water hygienically, and in other cases an excellent means, but on the average it is not entirely reliable." The writer agrees that the word should have been omitted, and in fact intended to have it stricken out, but it inadvertently was retained. Nowadays the real purpose of a filter of any kind is to clean the water thoroughly and dependably and this demands that it shall be so designed and controlled that derangements and deterioration of the apparatus shall be eliminated

to the fullest practicable extent. Mr. Johnson's closing remark that "the future will see its use to a far greater extent than in the past, for the treatment of practically any water, and in practically any amount" shows very full confidence in the capabilities of the more improved pressure filter.

Mr. Ledoux expresses regret that the author did not present data concerning the results obtained with various plants. The author is indebted to many water works men, and especially Mr. Ledoux, for information furnished upon request, and found this information very helpful. It was not tabulated in the paper for the reason that time was too short for the correspondence which would have been necessary to clear up certain doubts and prepare it for publication. Mr. Gwinn's discussion, which includes a comprehensive statement of the results obtained at Terre Haute, compensates for the omission, but the author is glad to add a tabulation of the data as received.

		ATLANTA, GA.	DAVENPORT, IA.	EAST JERSEY COAST WATER COMPANY	EUREKA, COL.	HOLMESBURG PA.
Capacity of plant (m.g.d.)		21.00	8.0	1.75	1.25	5.00
Average consumption (m.g.d.)		17.00	4.0	.....	.64	2.00
Source of water supply		Chattahoochee R. Storage Res'r	Miss. R.	.....	Elk R.	Pennypack C Sandy Run
Capacity of coagulating basin (gallons)		6,000,000	5,000,000	.....	32,000 to 90,000	1,000,000
Air agitation		No	Yes	.....	No	No
Sterilization		No	Yes	.....	Yes	Yes
Period covered by averages (yrs.)		.....	.....	.....	.....	1
Turbidity of applied water (p.p.m.)	Average	27	50	.....	80	20
	Maximum	135	.....	.....	500	6000
Bacteria per c.c. in applied water	Average	50§	.....	237	40§	9400
	Maximum	500§	.....	500	65§	200,000
Bacteria per c.c. in effluent	Average	6§	10 to 50‡	19	13§	31
	Maximum	500§	.....	50	70§	300

* The Media plant has just been improved by the addition of a 2,000,000 gallon sedimentation and coagulating b
‡ Incubated on gelatin at 20°.
§ Incubated on agar at 37½°.
φ Incubated on agar at 20°.

Operating Results of Various Pressure Filter Installations

ıA, COL.	HOLMESBURG, PA.	KINGSTON, N. Y.		MEDIA, PA.*	MILLEGE-VILLE, GA.	NESHAMINY, PA.	CONSOLI-DATED WATER CO. OF SUBUR-BAN, N. Y.
.25	5.00	3.0	3.0	1.00	0.75	2.50	.....
.64	2.00	2.70	2.30	0.60	0.25	1.00	.....
ı R.	Pennypack Cr. Sandy Run	Storage Res'r.	Storage Res'r.	Ridley Cr.	Creek	Neshaming Cr.	.....
to 90,000	1,000,000	None	None	50,000	100,000	160,000	.....
Ño	No	No	No	No	No	No	.....
es	Yes	Yes	Yes	Yes	.....	Yes	.....
.....	1	1	1	.....	.....	.....	.....
0	20	2	4	15	50	12	25
0	6000	.....	.....	1500	3000	2000	3000
0§	9400	2868‡	2517‡	700	300	150	500
5§	200,000	.....	.....	5000	3000	75,000	3000
3§	31	19‡	17‡	.....	15	4	20
0§	300	.....	.....	.....	32	50	100

tion and coagulating basin, a wash water tank, and loss of head and rate of flow gages.

HAMINY, PA.	CONSOLIDATED WATER CO. OF SUBURBAN, N. Y.	ONEONTO, N. Y.	PLANT NEAR PHILADELPHIA	RAHWAY, N. J.	ROCHESTER, N. Y.	STREATOR, ILL.	TERRE HAUTE, IND.
2.50	.....	3.00	5.00	6.00	6.00	3.50	8.00
1.00	.....	1.50	4.00	4.50	4.40	1.90	4.81
aming Cr.	.....	Storage Res'r.	Crum Cr.	Robinson Br. Imp. Res'r	Lake Ontario	River	Wabash R.
60,000	.....	None	300,000	None	.....	390,000	.....
No	.....	No	No	No	No	Yes	.....
Yes	.....	Yes	Yes	Yes	Yes	.....	Yes
.....	.....	.....	.....	.....	6	.....	5
12	25	20	15	10	12	200	111.6
2000	3000	.....	1500	90	121	4000	3000
150	500	300	700ϕ	350	4112	13,000	1667
,000	3000	.....	5000ϕ	3500	39,830	320,000	15,000
4	20	15	8ϕ	3	68	14	488
50	100	.....	50ϕ	275	2587	110	.....